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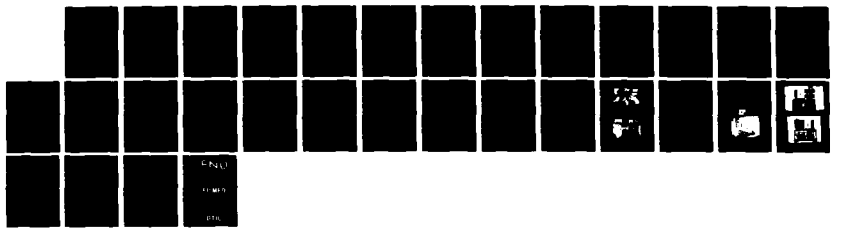

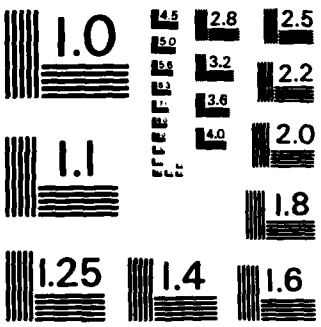

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Antimisting Kerosene: Development of A Continuous 10 GPM Inline Blender

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October 1985

Final Report

Prepared for
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Federal Aviation Administration

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16. Abstract

A continuous inline blender was developed at JPL to blend precisely metered quantities of ICI developed polymer slurries into a stream of Jet-A fuel. The inline blender was used to produce 5 to 10 gallons per minute of freshly blended AMK. The proprietary ICI slurries were made of FM-9 type polymers in a glycol/amine carrier fluid. Depending upon the polymer particle size and powder loading, the slurry consistency ranged from "free flowing" to a "paste" with viscosities in the range of 5000 to 100,000 centipoise. With one of the polymer slurries, a provision was made for a time delay between the addition of slurry and the addition of the amine sequentially into the Jet-A stream. Originator supplied keywords include:

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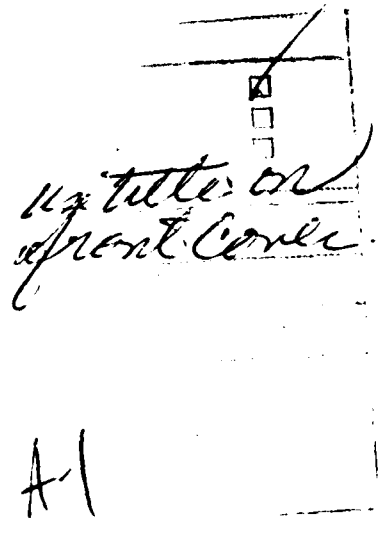

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

EXECUTIVE SUMMARY

A continuous inline blender was developed at JPL to blend precisely metered quantities of ICI developed polymer slurries into a stream of Jet-A fuel. The inline blender was used to produce 5 to 10 gallons per minute of freshly blended AMK. The proprietary ICI slurries were made of FM-9 type polymers in a glycol/amine carrier fluid. Depending upon the polymer particle size and powder loading, the slurry consistency ranged from "free flowing" to a "paste" with viscosities in the range of 5000 to 100,000 centipoise. With one of the polymer slurries, a provision was made for a time delay between the addition of slurry and the addition of amine sequentially into the Jet-A stream.

1.0 INTRODUCTION

The fire suppression performance of antimisting polymer additives in jet fuel has been demonstrated by many small and large-scale flammability tests and large-scale simulated crash tests. Studies have shown that production of FM-9 antimisting kerosene (AMK) fuel at refineries followed by its transfer to airport storage facilities and subsequent supply to aircraft fueling stations would require extensive modification of existing airport facilities at prohibitive cost (Reference 1). These traditional production and handling procedures will expose the AMK to the problems of unintentional degradation, exposure to bulk water, filtration difficulties, and shelf-life. The most practical approach for implementation of AMK worldwide is to produce the AMK at the fueling point by means of an inline blender.

When AMK is blended at the aircraft fueling point, the fuel must attain acceptable mist suppression and degradation properties within 15-30 minutes after blending. In light of this requirement, much of the quality control work during the research and development phase was performed on freshly blended fuels. This necessitated the availability of an inline blending device.

For the above two reasons, it was important to develop an inline blender which could demonstrate the inline blending concept and produce moderate quantities of freshly blended AMK for laboratory testing.

Development work on a continuous inline blender was undertaken at JPL in early 1983. The first field demonstration was conducted at Federal Aviation Administration Technical Center in February 1983. Improvements were made in the design following these tests. The improved version of the blender was used to produce AMK from FM-9 polymer slurry at the FAA Technical Center in April 1983. This freshly blended AMK passed the FAA wing spillage facility test at 140 knots airspeed. Following this successful demonstration, the inline blender was turned over to FAA. A second 10 gallon per minute (gpm) inline blender similar in design was built at JPL to support in-house AMK research.

The goal was to develop a blender that would rapidly disperse the polymer particles in the jet fuel stream and deliver a homogeneous suspension of fine polymer particles in the fuel. It should be noted that the dissolution of the polymer particles in jet fuel is a relatively slow process, with a characteristic time longer than the flow time through the blender.

Typically, in an AMK fueling operation, a suspension of polymer particles via a carrier fluid is mixed in jet fuel while being pumped into a wing tank by an inline blender. Once the wing tank is loaded, the suspension, with its cloudy appearance (Turbidity NTU = 40-50) slowly equilibrates while the turbidity value progressively decreases. Polymer particles slowly dissolve in the jet fuel by molecular diffusion because there is no stirring mechanism in the wing tank to promote dissolution by convective mixing. Current airport minimum service operation time dictate a level of equilibration which assures required flammability protection and degradability in 15 to 30 minutes after the completion of the blending/tank loading process.

The dissolution rate of polymer particles suspended in jet fuel may be increased by a continuous agitation of the suspension. Moderate agitation is acceptable but, there is a danger, of degrading the polymer already dissolved if the shearing action of any agitating mechanism is too severe. For this reason, the most desirable approach is to select a polymer dissolution rate and particle size in a suspension that achieves equilibration in the required time without need for further agitation after blending.

The polymer particle size in a slurry carrier fluid is very important in determining whether a homogeneous AMK will result following the dispersion of the polymer particles by the inline blender and subsequent equilibration in the absence of further agitation. In the case of large polymer particles in a quiescent suspension they tend to settle at the bottom of the container under the action of gravity. Such partially dissolved large particles are surrounded by a layer of "gel" containing high dissolved polymer concentration and have the appearance of a "fish eye". Upon settling, these "fish eyes" containing large partially dissolved polymer particles tend to coalesce, further reducing the interface area for molecular diffusion. This settling process results in a bulk solution with lower-than desired polymer concentration and reduced

flammability protection. Furthermore, a thick gel of partially dissolved polymer particles is formed at the bottom of the container that is very difficult to dissolve due to its dramatically reduced surface area. For these reasons, it is necessary to assure the polymer particles are of sufficiently small size to prevent such formations.

For a fixed polymer to glycol weight ratio in the slurry composition, decreasing the particle size leads to increased slurry viscosity, which changes the slurry characteristics from "free flowing" to a "paste". From slurry handling, injection, metering, and dispersion points of view, a "free flowing" slurry is far more desirable than a "paste". The free flowing characteristic may be imparted to a slurry of fine polymer particles by increasing the glycol content of the slurry, i.e., by reducing the slurry powder loading (Reference 2, 3).

Much of the development work on polymer particle size effects on slurry properties and blend homogeneity was done with the use of a small-scale inline blender which employed a static mixer to disperse polymer slurries injected from a syringe in a Jet-A fuel stream. The description of this small-scale blender is contained in Reference 4. Experience gained with this small-scale blender was valuable in the development of a continous, 10 gpm capacity inline blender described in this report.

The blender was designed to operate with all variant slurries. In some of these FM-9 variant slurries, amine was contained in the slurry. However with one FM-9 variant slurry, small-scale blender tests showed that a delayed addition of amine was beneficial in attaining superior flammability protection. The continuous inline blender described herein incorporated this delayed amine addition feature. When working with the other FM-9 polymer slurries that had the combined glycol and amine, this feature was not used.

2.0 DESIGN CONSIDERATIONS

The basic function of a continuous AMK inline blender is to disperse uniformly a metered quantity of a polymer slurry into a metered flow of Jet-A fuel to provide a homogeneous suspension of polymer particles in Jet-A fuel with a desired polymer concentration.

To achieve this basic function, three subsystems are needed:

1) Jet-A pumping and metering system
2) Slurry pumping and metering system
3) Mixing device to disperse polymer slurry in the Jet-A stream

Each of the three subsystems are described below.

2.1 Jet A Pumping and Metering System

For the purpose of providing a smooth flow, centrifugal and gear pumps were considered for pumping the Jet-A. Centrifugal pumps were rejected because of the significant dependence of flow rate on inlet and exit pressures. The inlet and exit pressures of the Jet-A pump are affected by several factors: level of Jet-A in the supply tank, changes in the pressure drop across the fuel filters, changes in the pressure drop across the mixing element when switching on the slurry supply, and the level of AMK in the discharge tank. To render the Jet-A flow relatively insensitive to changes in inlet and exit pressures, a gear pump was chosen. The gear pump was all bronze construction with a stainless steel shaft and a Teflon seal. It has a rating of 13.3 gpm at 20 psi delivery pressure at 1200 rpm with a shaft power requirement of 3/4 hp at this rating. Since a gear pump is nearly a positive displacement pump, flow control could be achieved by two means: a variable speed motor drive for the pump or use of a bypass loop in conjunction with a fixed speed motor drive. The second option was quickly eliminated because of the sensitivity of the bypass flow to the inlet and exit pressure variations. An adjustable speed d.c. system was chosen to power the gear pump. The motor was a 3/4 hp, totally enclosed, fan cooled, d.c. permanent magnet unit, powered from and regulated by a 115 V.a.c. controller.

The motor delivered a constant torque and developed its rated 3/4 hp at a maximum speed of 2500 rpm. To match the motor drive with the pump, a 2:1 speed reduction pulley drive was installed. (Figure 1.)

The Jet-A flow rate was measured by a 1-inch Fischer-Porter turbine flow meter installed downstream of the gear pump. In the range of 5 to 10

gpm Jet-A through the turbine flow meter, the corresponding signal frequencies were found to be linearly related to the flow rate. The reluctance signal from the turbine flow meter was conditioned by an amplifier and a band-pass filter, and displayed on an oscilloscope. The frequency was then measured by counting the number of cycles in 1-second intervals by means of a counter. The band pass filtering of the reluctance signal was found necessary to eliminate low frequency jitter and high frequency noise.

2.2 Slurry Pumping and Metering System

The slurry pump was required to provide a steady slurry injection rate of up to 375 cc/min at a delivery pressure up to 20 psig for slurries in the viscosity range of 5,000 to 100,000 centipoise. A "progressive cavity" rotary screw pump especially suited for pumping slurries was selected for this application. This pump is designed to be a positive displacement device, i.e., at a given speed, the flow rate should be independent of the delivery pressure. This was not found to be the case. With increasing delivery pressure at a fixed speed, the flow rate decreased slightly, due to leakage past the seal between the rotor and the stator. It was therefore necessary to calibrate the slurry flow rate as a function of the shaft speed and the expected delivery pressure under actual operating conditions.

The manufacturer's recommended pump speed for the viscous slurries to be pumped was rather low, less than 100 rpm for viscosities exceeding 10,000 cp. A speed controlled, 1/8 hp, DC motor drive with a 20:1 speed reducing gear box was used to power the slurry pump. (Figure 2.)

A 1/2 inch flexible hose was used to deliver the slurry from the pump to the injection tube. The injection tube was approximately 4 inches long with 1/4 inch inner diameter. This assured that most of the pressure drop in the slurry delivery line occurred in the injection tube. The pressure upstream of the injection tube was monitored by a pressure gage (0-60 psi). The slurry flow was calibrated as a function of the motor speed while maintaining the appropriate delivery pressure. The slurry flow calibration procedure is discussed further in Section 4.

2.3 Dispersion of Polymer Particles in Jet-A Flow

Once a metered quantity of slurry is introduced into the metered Jet-A stream, it is necessary to mix the slurry and the Jet-A fuel as rapidly as possible to disperse the individual polymer particles uniformly into the Jet-A stream. If this is not done immediately after the slurry injection, relatively large blobs of slurry could become encased in thick, high polymer concetration gel. Upon leaving the blender, these blobs of gel would leave the bulk fuel with unacceptable flammability protection and coat the fuel tank surface with a layer of thick, high polymer concentration gel.

The rapid dispersion of polymer slurry in the Jet-A flow was accomplished by use of an inline static mixer immediately downstream of the injection point. This mixer contained no moving parts but had internally inserted helical elements that turned the flow alternately clockwise and counterclockwise as the fuel progressed through the mixer. (Figure 3.) The recommended Reynolds number based on the mixer inside diameter was well into the turbulent regime. The number of helical elements was selected from manufacturer's design data (see calculations in Appendix A.) The mixing tube diameter was chosen to provide high enough Reynolds number (5000 to 30,000) for good mixing, while not resulting in excessive pressure drop at the design flow rates (1 to 5 gpm through the mixer). The pressure drop through the mixing tube was limited to 10 psig maximum. This was necessary to assure satisfactory operation of the slurry pump which injected the slurry upstream of the mixing tube.

To further promote slurry breakup in the Jet-A stream immediately after injection, a single helical element was inserted in the Jet-A line directly upstream of the slurry injection point as shown in Figure 4. This device imparted a strong swirl component to the Jet-A flow shortly before contacting the slurry and assisted in rapid breakup and dispersion of the injected slurry in the Jet-A stream. The mixing and dispersion process then continued in the static mixing tube.

A list of the blender hardware parts selected is given in Appendix B.

3.0 BLENDER DEVELOPMENT

The subsystem, components (the pumping and metering for Jet-A and slurry and the mixing for slurry dispersion) were assembled as shown schematically in Figure 5. The system was designed to provide blending of FM-9 slurry with amine as well as slurry with delayed amine addition.

When blending FM-9 slurry with amine, all the Jet-A flow passed through the slurry injection leg of the system. When the amine is withheld from the slurry, part of the Jet A flow passes through a second leg (amine injection leg) of the system.

3.1 FM-9 Configuration With Separate Amine Constituent

The key design requirement for inline blending of the FM-9 polymer was the addition of amine separately to the polymer dispersion with a delay of 1 minute or more after the polymer-glycol slurry was dispersed into the JetA stream. In small-scale blending experiments using the inline blender, this delayed amine addition was found to impart superior flammability protection to the AMK produced.

The 1-minute delay was achieved by splitting the Jet-A flow into two legs: the primary or slurry injection leg and the secondary or amine injection leg of the system, enough volume capacity was added so that the flow time of the polymer suspension in Jet A was about 1-minute. The required amount of amine was introduced into the Jet-A in the secondary leg. The two flows, one containing glycol and polymer and the other containing amine, were then brought together and mixed in an inline static mixer. In this manner, the 1-minute delay between the addition of polymer and addition of amine was achieved.

The advantage of splitting the Jet-A flow along two legs was that it reduced the flow rate through the primary leg, therby reducing the volume capacity needed to achieve the 1-minute delay. At first, a 5-gallon stainless steel container was installed in the primary leg after the static mixer. This proved unsatisfactory for two reasons: first, a plug flow (uniform velocity at each cross-section) could not be established in

this container to result in the required 1-minute flow time and second, the recirculating flow pattern in the container caused settlement of larger slurry particles which formed a thick gel within the container.

An improved design was developed to provide both the 1-minute flow time and to promote further dissolution of larger polymer particles. In this design, output of the polymer suspension from the static mixer was passed through 120 feet of transparent 1-inch Tygon tubing, which was coiled to fit into a box 2 ft x 2 ft x 4 ft. The flow speed was approximately 2 ft/sec through the tube, giving the required 1-minute flow time. To promote dissolution of the larger polymer particles during the flow through the Tygon tubing, six static mixers fabricated by JPL were inserted in the Tygon tubing at 20-ft intervals. These mixers were fabricated from 1 inch stainless steel tubing and each contained a pair of helical elements to provide gentle stirring of the polymer suspension, aiding the dissolution process without causing significant degradation of the polymer already in solution. This device worked quite well in assisting the dissolution of suspended polymer particles in the fuel as evidenced by the decrease in the turbidity.

After the passage through the Tygon tubing, the Jet-A polymer flow leg was mixed with the Jet-A/amine into a short, static mixer fabricated from 1 inch stainless steel tube containing four helical elements.

The amine was supplied from a nitrogen pressurized chamber via a needle valve and a rotameter (Figure 5). It was injected into the Jet-A stream of the secondary leg through a 1/8 inch stainless steel tubing, inserted in the Jet-A line with a 90° bend. A short static mixer was installed downstream of the amine injection point.

A turbine flow meter was installed in the secondary leg, upstream of the amine injection point. The primary flow rate was derived from subtraction of the second flow from the total flow, both of which were measured with turbine flow meters. Generally, the flow was split equally between the primary and the secondary legs. A system of check valves was added, to prevent back flow of AMK and/or gel into the turbine flow meters.

3.2 FM-9 Configurations with combined Glycol and Amine Constituents

For the blending of those FM-9 slurries with combined glycol and amine, the configuration was simplified. For operation in this mode, the ball valve on the secondary leg of the blender was shut off, causing all of the Jet-A flow to go through the primary (slurry injection) leg.

When using one of these FM-9 slurries in which the polymer particle size was large enough to cause settlement and gel formation in the receiving tank after discharge from the blender, the 120 ft. length of Tygon tubing with the two element static mixers was added to the primary leg of the blender to aid in the dissolution of the larger polymer particles. However, the best way to minimize or eliminate this settlement was to control the polymer particle size in the slurry.

For the other FM-9 combined glycol and amine slurries, the polymer particle size was small enough so that even when the flow was discharged directly into the receiving tank after the static mixer, the polymer particles remained in suspension and no settlement problems were encountered. Therefore, the 120 ft coil of 1 inch Tygon tubing was bypassed when blending these FM-9 slurries.

3.3 Development of Slurry Feed System

No significant problems were encountered in pumping slurries even with the consistency of a paste, provided the rotary screw slurry pump was properly primed and continuously supplied with slurry at the pump inlet. Supplying the slurry to the pump inlet without interruption, however, proved to be a challenging task for slurries with consistency of a paste (viscosities in the rage 50,000 to 100,000 centipoise). The slurry supply container was connected to the pump inlet thru a 1-inch Tygon tubing. The pump by itself provided enough suction to draw the slurry paste from the supply container. However, the slurry flow in the container was nonuniform, leading to the formation of an air passage in the tube connected to the pump inlet, resulting in loss of pump suction.

It was also difficult to pack the slurry paste in the supply container without any trapped air bubbles. The ingestion of these trapped air bubbles soon caused loss of pump suction. The problem could be ameliorated to some extent by constant manual agitation of the slurry. However, there was always the potential for loss of pump suction with a consequent interruption in slurry injection. Metering of the slurry flow during calibration also was a problem in the presence of air bubbles trapped in the slurry paste.

The solution for the slurry feeding problems was to dilute the slurry with additional glycol so that the glycol to polymer ratio was increased relative to the original composition. This made the slurries of all polymers free flowing. Tests on AMK blended with slurries containing extra glycol showed no effect on flammability, degradability, low temperature behavior, pumpability, etc. Therefore, thinning of the slurry with extra glycol was adopted as the interim solution to the pump feeding problems. The manufacturer was instructed by FAA to attack this problem so that the amount of glycol could be decreased in the production system.

The slurry was injected into the Jet-A stream directly upstream of the static mixer through a 3/8 inch outside diameter stainless steel tube. The tube end was cut at a 45° angle facing downstream at the center of a pipe cross (Figure 4). The fitting at the Jet-A inlet end of the cross contained a single helical element insert to impart a swirl to the incoming Jet-A stream. The downstream end of the cross was directly connected to the 1/2-inch Kenics static mixer. The slurry injection tube was inserted from the top leg of the cross. The bottom leg of the cross contained a dead-end tube extension. The purpose of this extension was to collect any slurry that continued to drip from the slurry injection tube after the Jet-A was turned off. Without a collection tube, the dripping slurry would accumulate in the flow passage and would form a high polymer concentration gel that would create a blockage problem. The extension tube was periodically taken out and cleaned.

A ball valve was located upstream of the 4-inch long extension tube to prevent the Jet-A from flowing back into the slurry supply line and

forming gel. At the beginning of each run, the injection tube was cleaned out to remove any gel. Further upstream from the ball valve a 0-60 psig pressure gauge was mounted on the slurry line. The slurry pump speed and the slurry pressure were used as independent parameters for slurry flow calibration.

Photographs of the JPL built continous inline blenders are shown in Figures 6, 7(a) and 7(b).

4.0 FLOW METERING AND CALIBRATION PROCEDURE

The two turbine flow meters: one measuring total Jet-A flow through the blender and the other measuring the flow through the bypass (amine injection) leg, were calibrated in place. The ball valve on the slurry injection leg was shut off during calibration so that the same flow passed through each flow meter. The outflow from the blender was collected in a weigh tank. The flow rate was altered by changing the speed of the gear pump. At different speed settings of the gear pump, the flow into the weigh tank was timed and corresponding turbine flow meter frequency readings were noted. The mass flow rate was determined from the change in the weight of the collection tank over a known time interval. The volume flow rate was then derived from fuel density, which is a known function of temperature. Typical calibrations are shown in Figure 8.

The calibration of the slurry flow rate depended both on the pump speed and the delivery pressure. For the purpose of slurry flow-rate calibration, the slurry injection tube was withdrawn from the Jet-A line, and the slurry flow was collected in a beaker over a measured time interval. The flow rate was determined by weight gain of the beaker over a known time interval. During this calibration, the slurry was being discharged at atmospheric pressure, rather than into a higher pressure environment during discharge into the Jet-A line under blender operating conditions. To eliminate this error, the ball valve in the slurry feed line was partially closed during slurry flow calibration to build up a slurry pressure upstream of the valve to the same pressure that would exsist in the Jet-A line during blender operation. Using this procedure it was possible to keep the uncertainty in the slurry flow rate measurement within ± 6 percent of the desired flow rate.

5.0 OPERATING PROCEDURE

(For FM-9 combined glycol and amine constituent slurry blending)

1. Homogenize slurry for at least four hours by placing the slurry container on a tumbler.
2. Connect Jet-A supply.
3. Fill the slurry reservoir with homogenized slurry.
4. Calibrate the slurry flow rate using procedure in Section 4.
5. Place the slurry injection tube in position after calibration is performed.
6. Have a waste barrel ready to collect blender discharge during start up and shutdown.
7. Turn on Jet-A pump and adjust controller until desired total flow meter frequency reading is obtained. (The Jet-A motor controller may need further minor adjustments as the motor warms up).
8. Turn on the slurry pump at the calibrated speed setting.
9. After turning on the slurry pump, immediately open the ball valve on the slurry injection tube.
10. Wait until steady Jet-A and slurry flows are established, as evidenced by the turbine flow meter frequency output and the slurry injection pressure.
11. Start collection in a clean barrel.

Shut Down Sequence

1. Transfer discharge hose into a waste barrel.
2. Shut off the ball valve on the slurry injection.
3. Immediately turn off the power to the slurry pump motor.
4. Turn off power to the Jet-A motor.
5. Continue to flow Jet-A without slurry injection for at least one minute to flush the system.

6.0 RESULTS

The quality of the AMK produced by the continous inline blender was evaluated by several quality control tests:

1) Flammability test
2) Filter ratio test
3) Cup test
4) Turbidity (NTU) test
5) Solid (FM-9) content test

All these tests were conducted at several time periods after the completion of a blending run.

The flammability test used was the wing spillage facility at the FAA Technical Center when blending was performed there. For blending runs performed at JPL, the "miniwing shear" fire test was used. The JPL flammability test employed a continous oxy-acetylene torch and it was slightly more conservative than the FAA wing spillage facility. Results obtained with these FM-9 slurries are tabulated in Table 1.

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TABLE I

EVALUATION OF AMK BLENDED IN JPL 10 GPM INLINE BLENDER

DATE	SLURRY LOT AND BASE FUEL	FIRE TEST (Fuel Temp)	FILTER RATIO FR	CUP TEST CT	SOLIDS %
11/13/84	CID COMPOSITE SLURRY IN CID JET A	PASS AT 30 min. 130 Knots,(20°C)	FR 50 min = 52 FR 120 min = 63 FR 24 hrs = 75	CT 120 min = 1.9 CT 24 hrs = 1.9	0.296
10/15/84	JCK 16-95-2 TEX/BURB SEPT 84 JET A	PASS AT 30 min. 130 Knots,(25°C) PASS AT 30 min. 160 Knots,(25°C)	FR 24 hrs = 85	CT 24 hrs = 1.8	0.31
09/03/84	JCK 16-88-3 TEX/BURB AUG 84 JET A	FAIL AT 15 min. 130 Knots,(24°C) PASS AT 60 min. 130 Knots,(24°C) MARG AT 80 min. 130 Knots,(31°C) FAIL AT 110 min. 130 Knots,(33°C) PASS AT 8 days 130 Knots,(26°C)	FR 4 hrs = 81	CT 40 min = 2.1 CT 24 hrs = 1.9	0.31
08/06/84	JCK 14-247-1 TEX/BURB AUG 84 JET A	MARG AT 20 min. 130 Knots,(22°C) PASS AT 6 hrs. 130 Knots,(15°C)	FR 60 min = 56	CT 60 min = 1.95	0.31
08/04/84	JCK 14-247-1 TEX/BURB JET A	FAIL AT 25 min. 130 Knots,(26°C) PASS AT 24 hrs. 130 Knots,(21°C)	FR 40 min = 49 FR 9 days = 53	CT 18 min = 3 CT 30 min = 2.3 CT 9 days = 2.2	0.28

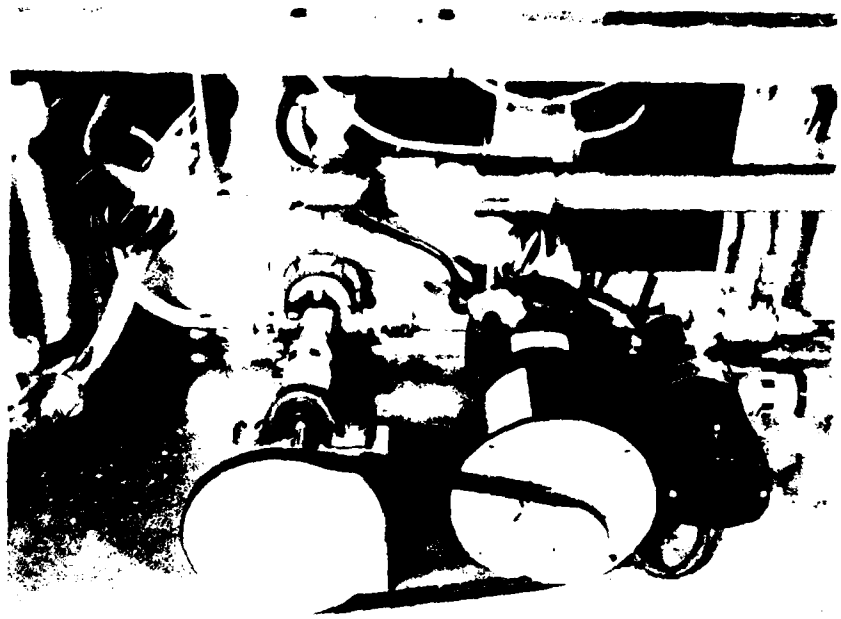


Figure 1 Photograph of gear pump and speed controlled DC motor drive

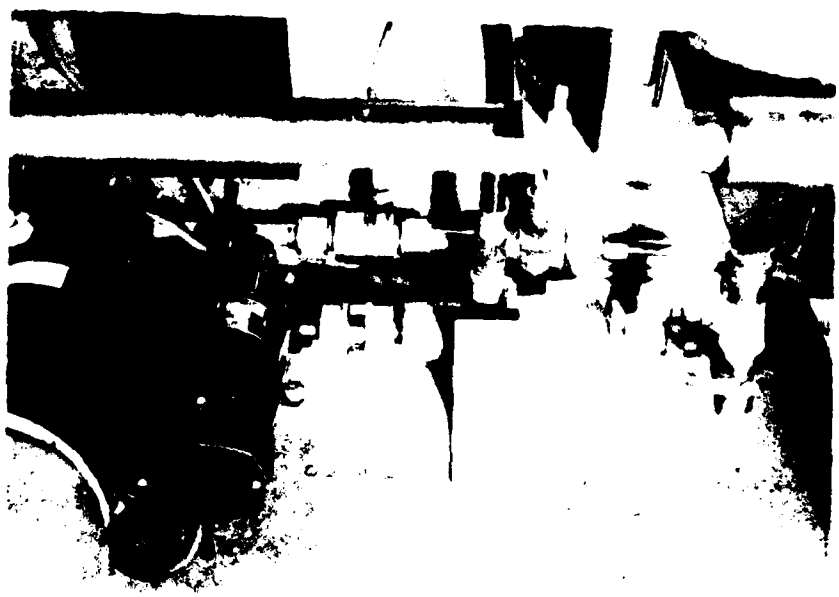
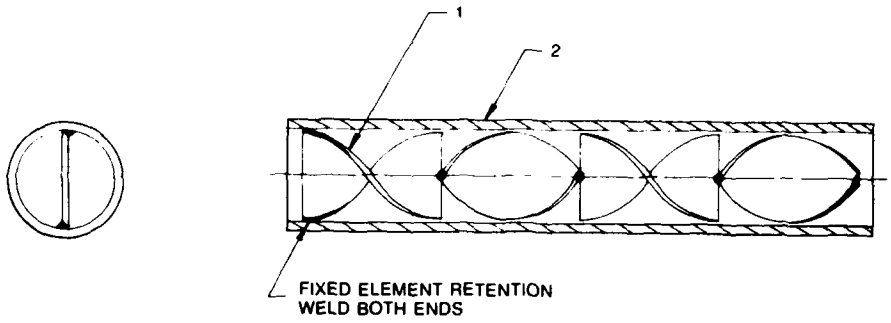


Figure 2 Photograph of slurry pump and speed controlled DC motor drive.



ITEM	DESCRIPTION	MAT'L
1	Element Assembly	[1]
2	Housing	[1]

BASE MIXER w/PLAIN ENDS [2] [3]

Figure 3 Cross-sectional view of Kenics Static Mixer

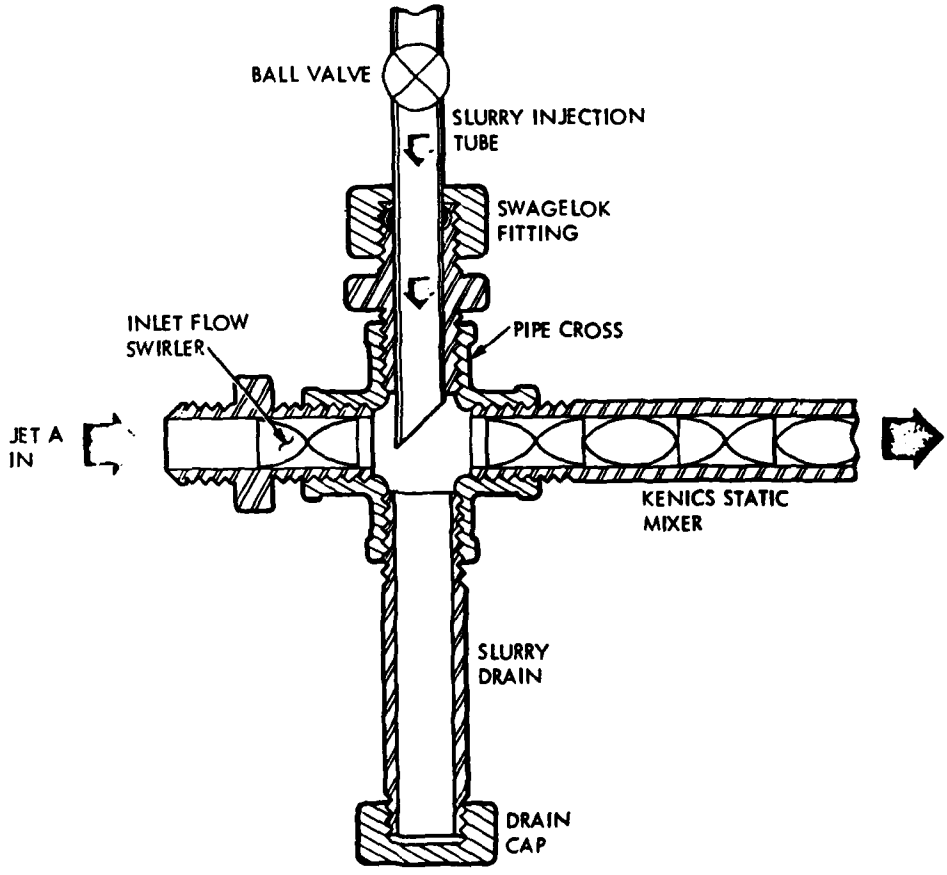


Figure 4 Details of slurry injection and dispersion scheme

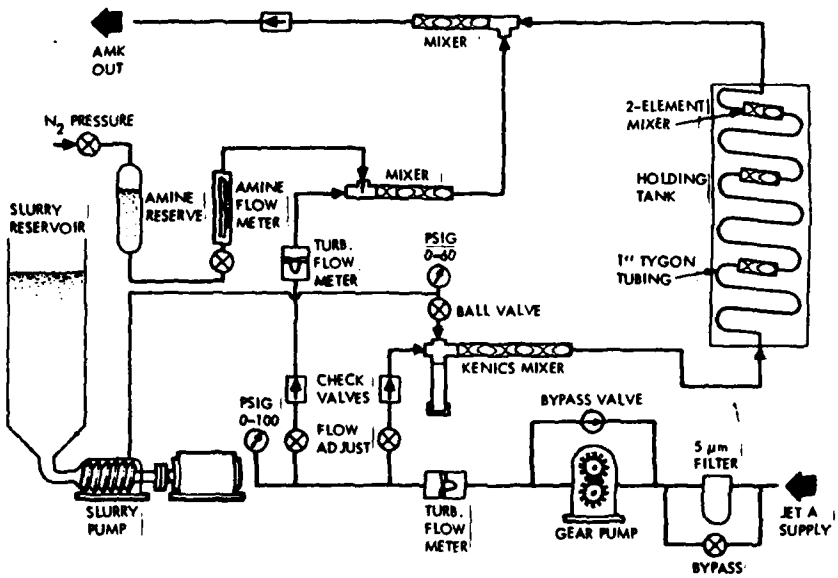


Figure 5 Schematic of the Inline Blender System

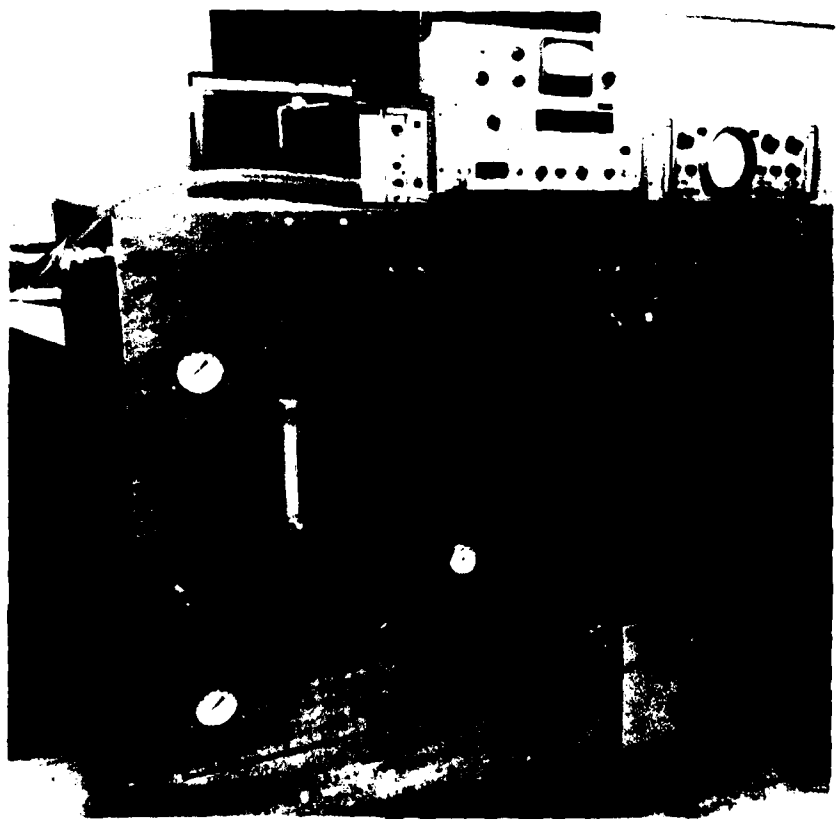


Figure 6 Photograph of JPL Inline Blender No. 1

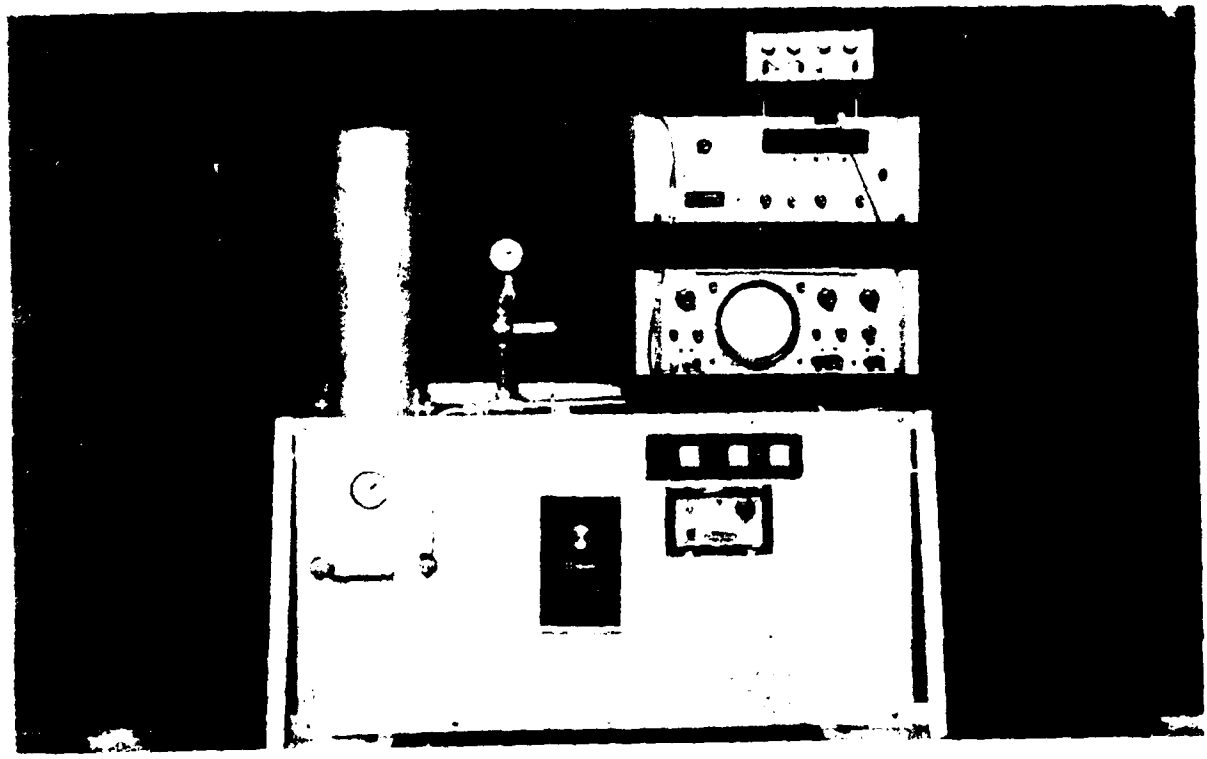


Figure 7a Photograph of JPL Inline Blender No. 2., front view

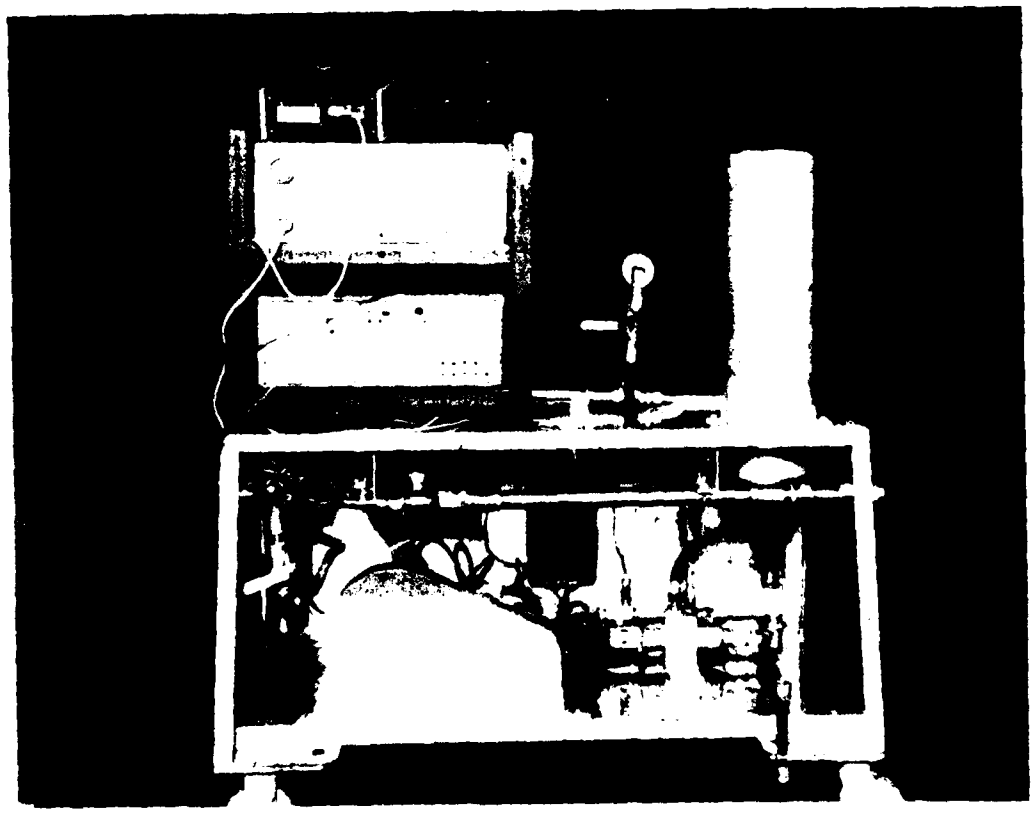


Figure 7b Photograph of JPL Inline Blender No. 2., back view

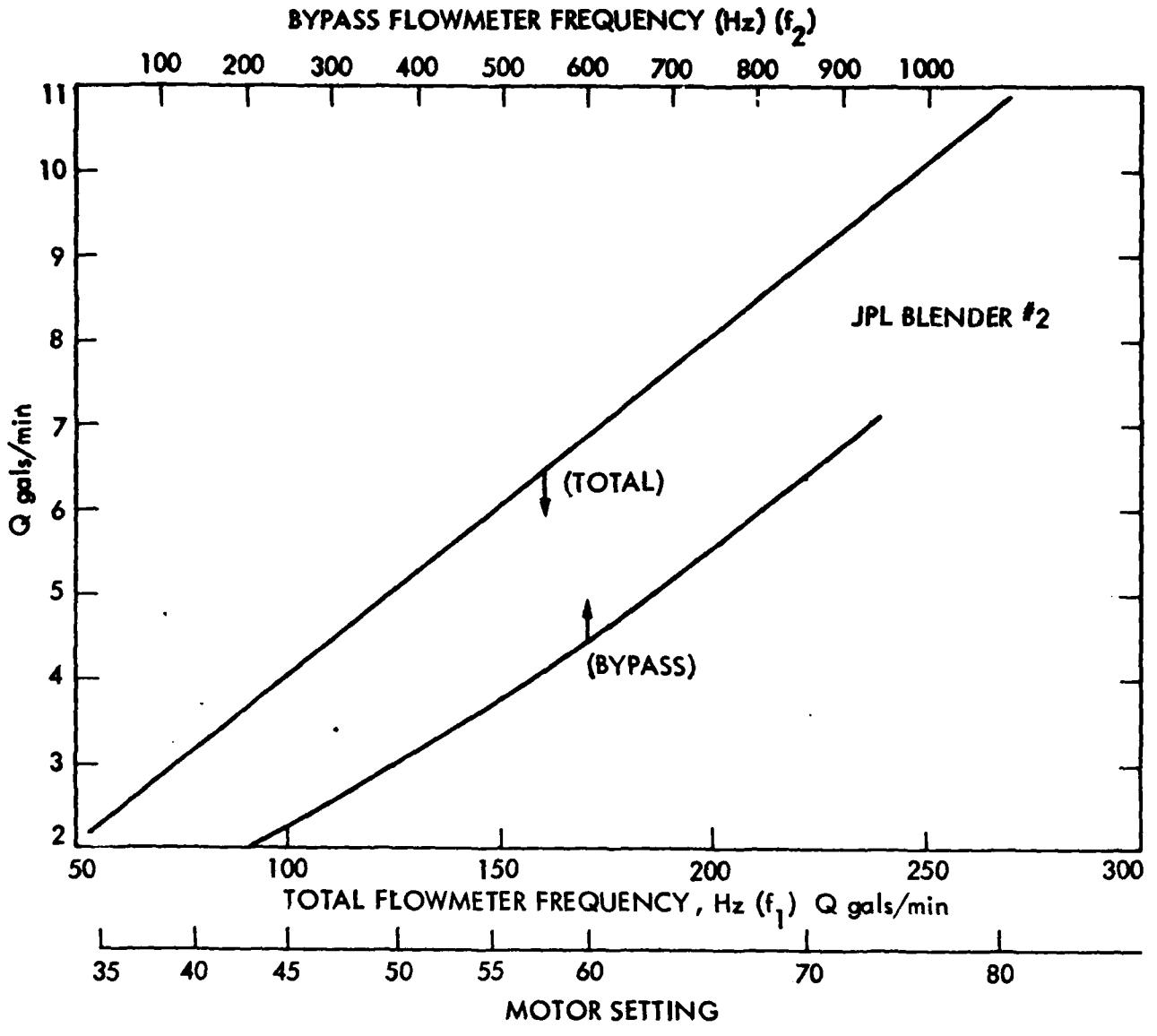


Figure 8 Turbine flow meter calibrations for JPL continuous Inline Blender No.2

APPENDIX A

Static Mixer Selection

Design flow rate range through mixer =

$$Q = 1 \text{ to } 5 \text{ gpm}$$
$$= 0.00223 \text{ to } 0.0112 \text{ ft}^3/\text{sec}$$

Static mixer inside diameter D = 0.5 in
= 0.0417 ft

Flow velocity range: $V = \frac{4Q}{\pi D^2} = 1.64$ to 8.16 ft/sec

Reynolds number range: $Re_D = \frac{VD}{\nu} = 5500$ to 28000

using kinematic viscosity for Jet-A at 15°C: $\nu = 12 \times 10^{-6}$ ft^2/sec

Thus the flow inside the mixing tube is well into the turbulent regime over the specified range.

The manufacturer recommends a single module containing 6 elements (Reference 4).

Pressure Drop Calculations:

$$(\Delta P)_{KM} = 45x(\Delta P)_o \text{ for turbulent flow, } Re_D > 2000$$

where $(\Delta P)_{KM}$ = Pressure drop across the kenics mixer.

$(\Delta P)_o$ Pressure drop across a tube of the same inside diameter.

Now, $(\Delta P)_o = \frac{fL}{D} \frac{\rho V^2}{2g_c}$

Where,

f = Darcy's friction factor $\approx$ 0.02 for the Re_D range here.
L = Mixer length (12 in.)
D = inside diameter (1/2 in.)
ρ = Jet-A density = 50 lbm/ft^3
V = flow velocity (in ft/sec)
g_c = gravitational constant (32.2)

$(\Delta P)_{KM}$ ranges from 0.32 to 8.1 psi for flow rate range 1 to 5 gpm.

APPENDIX B

AMK Blender Parts List

PART	SPECIFICATIONS	MANUFACTURER
Fuel Filter	25 Micron (#CT 101-BS 75)	AMF-Single Cartridge
Gear Pump	9.8 GPM at 900 RPM 13.8 GPM at 1200 RPM 20 psi delivery pressure 3/4 HP requirement	Teel Model 1P769
Gear Pump Motor	Permanent Magnet DC Motor 3/4 HP, 2500 RPM, 102 VDC Armature. Totally enclosed, fan cooled, continuous duty controller: 115 Vac single phase, 60 Hz.	Dayton Model 2Z846A
Turbine Flow Meter	Model #10 C1501 (3/4 in.) #10 C305 (1/2 in.)	Fischer-Porter
Kenics Static Mixer	Model #1/2 KMS 12(1/2 in.)	Chemineer-Kenics
Slurry Pump	Rotary Screw Pump Max. Speed 1725 RPM Max. Discharge Press 40 psig	Teel Model 1P610
Slurry Pump Motor	Permanent Magnet Gear Motor 1/8 HP, Gear ratio 20:1	Bodine Electric Model 142

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